Low-Noise Stimulated Brillouin Lasing in a Microrod Resonator

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Abstract: We demonstrate a Brillouin microcavity laser based on a microrod resonator exhibiting a frequency noise of 140 Hz/√Hz at 10 Hz offset. The corresponding laser linewidth is measured to be below 400 Hz.

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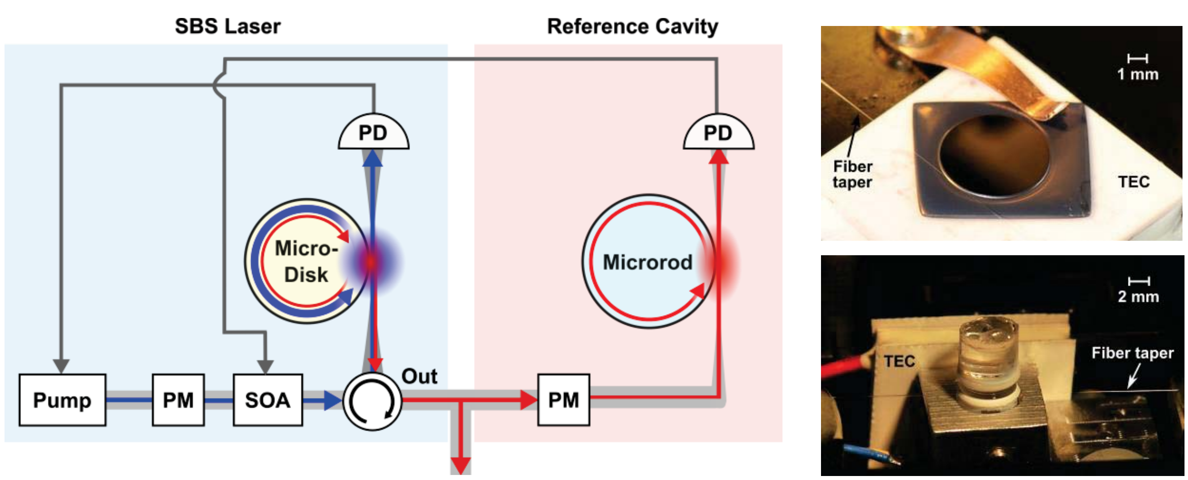
The stimulated Brillouin scattering (SBS) process acts as an ideal source of gain for lasers as it provides the capacity for lasing with the powerful combination of high signal levels and low noise. These properties of SBS gain are often exploited to produce free-running lasers with linewidths below 1 kHz in bulk fiber ring resonators [1]. Recently, SBS lasers have also been demonstrated in high-Q whispering-gallery mode resonators with the advantages of dramatically reduced size (6 mm diameter) and low optical pumping powers (~5-10 mW) [2–4]. With these advances, it now appears possible to bring a level of spectral purity beyond that of fiber and solid-state lasers into a compact centimeter-scale package. Aside from the fundamental limits of the SBS white noise which yield a < 1 Hz Lorentzian linewidth [3], the SBS microresonator lasers ultimately become limited by effects of thermorefractive noise at lower offset frequencies [5]. Previously we demonstrated a low-noise SBS microdisk laser [3, 4] that we stabilized to a microrod reference cavity [6, 7] in order to improve the laser's performance close to carrier. Here, we combine the microrod reference and the SBS laser into a single system that directly generates SBS lasing within the microrod resonator. We show that the stability of the microrod improves the SBS laser noise by two orders of magnitude at low offset frequencies, which we believe to be due to the microrod's larger mode volume.

Figures 1(a) and (b) show schematics of our previously demonstrated SBS microdisk laser system locked to a microrod reference cavity [4]. We refer to this configuration as our dual-microcavity SBS laser, and some photographs of the individual microdisk and microrod components are provided in Fig. 1(c). A commercial integrated planar external-cavity diode laser serves as the pump source which is sent through an external phase modulator (PM), a semiconductor optical amplifier (SOA), and a circulator before being coupled into the microdisk through a tapered fiber. The transmitted laser light is then photodetected (PD) with the resulting signal used as feedback for Pound-Drever-Hall stabilization of the pump laser onto the cavity resonance. The generated SBS signal (P = 1.9 mW, λ = 1550 nm) is collected in the backwards direction through the circulator, and part of the light is used for Pound-Drever-Hall stabilization to a microrod reference cavity via control of the SOA power. We are



(a) (b) (c)

Figure 1. Schematic of a (a) SBS microdisk laser system locked to a (b) microrod reference cavity system. Photographs of the microdisk and microrod resonators are shown in (c).

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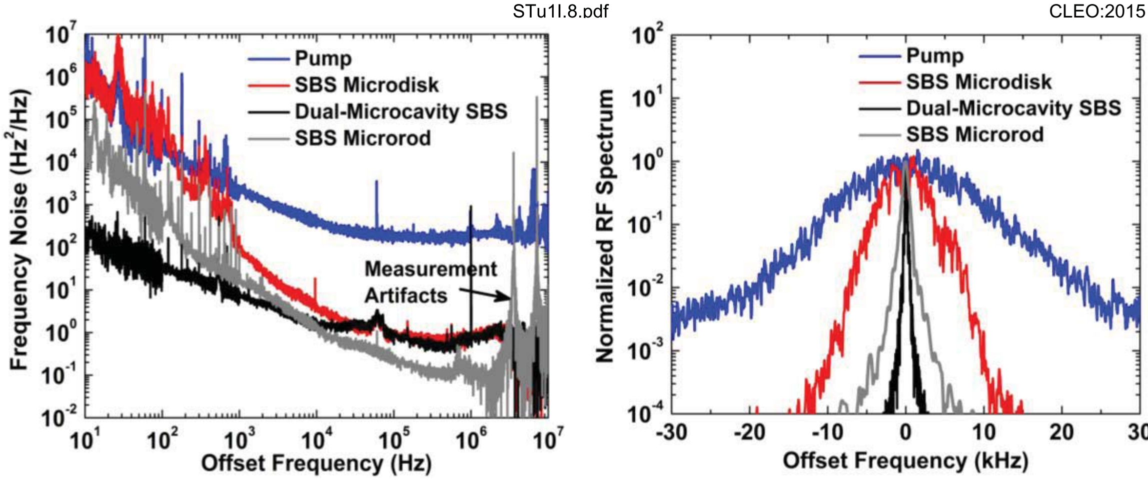

(a) (b)

Figure 2. Measured SBS microrod laser (a) frequency noise and (b) RF spectrum. The corresponding measurements for the pump laser (blue line), the SBS microdisk laser (black dashed line), and the dual-microcavity SBS laser are also shown and were obtained from Ref. [4].

interested here in simplifying the combined system of Figures 1(a) and (b) into a single SBS laser that replaces the microdisk resonator with the microrod reference cavity. To achieve the 11-GHz free-spectral range required for efficient SBS generation, we first start with a 6-mm diameter microrod and then subsequently trim the diameter slightly below 6 mm. The microrod fabrication is performed by mounting a fused silica glass rod on a rotating lathe and then subsequently cutting a resonator into the rod using a CO_2 laser.

Figure 2(a) shows a measurement of the SBS microrod laser's frequency noise. We compare this noise to that of the pump laser, the SBS microdisk laser, and finally to the dual-microcavity SBS laser. We measure the frequency noise using a combination of direct comparison with a cavity-stabilized 1-Hz linewidth fiber laser for low offset frequencies and a Mach-Zehnder interferometer for higher offset frequencies. Near the harmonics of 3.6 MHz, the sensitivity of the Mach-Zehnder measurement drops to zero, which introduces spurious artifacts in the measured frequency noise. Nevertheless, we observe that the SBS microrod laser is 2-3 orders of magnitude lower in noise compared to the pump laser and also improves on the SBS microdisk laser's low frequency noise by a factor of 100. The SBS microrod laser reaches a frequency noise of 2×10^4 Hz^2/Hz (140 Hz/$\sqrt{Hz}$) at 10 Hz offset. This level of noise is still two orders of magnitude higher than that of the full dual-microcavity system, and future efforts will be directed towards improving this noise further. At higher offset frequencies, the SBS microrod laser reaches a noise floor of 0.1 Hz^2/Hz (0.3 Hz/$\sqrt{Hz}$). Figure 2(b) shows the RF spectrum obtained from the photodetected beat between the SBS microrod laser and the 1 Hz cavity-stabilized fiber laser. The SBS microrod laser exhibits a half-power linewidth of <400 Hz, while the pump, SBS microdisk, and dual-microcavity SBS lasers exhibit half-power linewidths of 7.9 kHz, 3.3 kHz, and 95 Hz, respectively. The linewidth of the 6-mm microrod SBS laser is better than that of most fiber and solid-state lasers and thus highlights the unique advantages of using SBS gain for lasing in a microresonator.

In conclusion, we demonstrate a SBS microcavity laser that achieves high spectral purity by lasing off of a stable microrod resonator. Through this configuration, we demonstrate two orders of magnitude improvement in the SBS laser's frequency noise compared to both the pump laser and a SBS microdisk laser operating under similar conditions. By measuring against a 1-Hz linewidth reference laser, we determine the SBS microrod laser's linewidth to be better than 400 Hz.

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